The weight of the core (which may be varied), determines the force of current that has to pass through the regulating coil in order to keep the weight in suspension, and this in its turn is dependent upon the resistance of the arc. The result is that the length of the arc is regulated automatically, so as to maintain a uniform resistance signifying a uniform development of light.

III. "On the Influence of Electric Light upon Vegetation, and on certain Physical Principles involved." By C. William Siemens, D.C.L., LL.D., F.R.S. Received March 1, 1880.

Although according to Ste. Claire Deville the dissociation of CO_2 and H_2O at atmospheric pressure commences at a temperature not exceeding 1,200° C., the reverse action, namely, combustion, continues to be sufficiently active to increase the heat of a flame until a temperature of probably 2,200° C. is reached, of which the Deville oxygen blast and the regenerative gas-furnace furnish examples.

In the working out of a process, by means of which steel and fused iron are produced in large masses on the open hearth of the regenerative gas-furnace, I have had frequent opportunities of observing the utmost limit of temperature practically attainable by means of the combustion of carbonaceous substances. The heat of that furnace is not dependent upon a blast or upon chimney draught, and the pressure within the furnace balances the external atmospheric pressure so completely that the large working doors may be opened occasionally for inspecting the metal. On these occasions it may frequently be observed that serrated clouds of highly heated combustible gases pass through the furnace chamber (as may be seen through obscured or coloured glasses) without suffering apparently any diminution through contact with an excess of heated oxygen, showing that the limit of furnace heat, or the point of complete dissociation, has been nearly reached.

When thus brought face to face with the utmost limit of heat attainable by combustion, it is surprising how slight is the inconvenience (in the absence of heated matter flying about) experienced in approaching the open furnace, and how much higher must be the temperature of the sun or of the electric arc when the effects of distant radiation suffice to break up compounds such as nitrate of silver in a few seconds. Some years ago I undertook certain experimental inquiries having for their object to study the effect of radiant energy upon the ordinary products of combustion, CO_2 and H_2O, presenting them in an extremely rarefied conditon to solar and electric

radiation, which inquiries were not however carried far enough to furnish absolute results. They served me, however, for a stepping stone to the subject of my present communication.

The vast development of vegetation proves that dissociation is accomplished freely within the leaf-cells of plants, in which both water and carbonic acid are broken up in order that chlorophyl, starch, and cellulose may be formed. It is well known that this reaction depends upon solar radiation; but the question may fairly be asked whether it is confined to that agency, or whether other sources of light and heat, which in common with the sun exceed the temperature of dissociation, may not be called into requisition, in order to continue the action of growth, when that great luminary has set or is hidden behind clouds?

About two years ago I mentioned to Sir Joseph Hooker, then President of the Royal Society, that I thought the electric arc might be found sufficiently powerful to promote vegetation, and that I should be willing to undertake some experiments on the subject, if he could give me any hope of confirmative results. Sir Joseph Hooker gave me sufficient encouragement to induce me to follow up the subject, and I have since that time gradually matured a plan for conducting the experiment. Operations were commenced only at the beginning of the year, and although the results are necessarily incomplete, they are nevertheless sufficiently positive and remarkable to make them perhaps acceptable to the Royal Society as a preliminary communication on the subject. I was induced to look for interesting results in these experiments on account of the great abundance of blue and actinic rays in the electric arc, upon which its value in photography depends. In experimenting with powerful electric lamps for illuminating purposes, I have been struck moreover by the action produced upon the skin, which is blistered, without the sensation of excessive heat at the time, an effect analogous to that produced by solar rays in a clear atmosphere.

Effect of Radiant Energy on Plants.

The apparatus which has been put up at Sherwood consists—1. Of a vertical Siemens dynamo-machine, weighing 50 kilos., with a wire resistance of 0·717 unit on the electro-magnets. This machine makes 1,000 revolutions a minute, it takes 2 horse-power to drive it, and develops a current of 25 to 27 webers of an intensity of 70 volts. 2. A regulator or lamp, constructed for continuous currents, with two carbon electrodes of 12 millims. and 10 millims. diameter respectively. The light produced is equal to 1,400 candles measured photometrically. 3. A motor, which at present is a 3 horse-power Otto gas-engine, but which it is intended to supersede by a turbine to be worked by a natural supply of water, at a distance of about half a mile from the house.

Experiments on Effect of Electric Light on Plants.

My object in making these experiments was to ascertain whether electric light exercised any decided effect upon the growth of plants. For this purpose I placed the regulator in a lamp with a metallic reflector, in the open air, about 2 metres above the glass of a sunk melon house. A considerable number of pots were provided, sown and planted with quick-growing seeds and plants, such as mustard, carrots, swedes, beans, cucumbers, and melons. The plants could then be brought at suitable intervals under the influence of daylight and electric light, without moving them, both falling upon them approximately at the same angle. The pots were divided into four groups.

1. One pot of each group was kept entirely in the dark.
2. One was exposed to the influence of the electric light only.
3. One was exposed to the influence of daylight only.
4. One was exposed successively to both day and electric light.

The electric light was supplied for six hours, from 5 to 11 each evening, all the plants being left in darkness during the remainder of the night.

In all cases the differences of effect were unmistakable. The plants kept in the dark were pale yellow, thin in the stalk, and soon died. Those exposed to electric light only showed a light-green leaf, and had sufficient vigour to survive. Those exposed to daylight only were of a darker green and greater vigour. Those exposed to both sources of light showed a decided superiority in vigour over all the others, and the green of the leaf was of a dark rich hue.

It must be remembered that, in this contest of electric against solar light, the time of exposure was in favour of the latter in the proportion of nearly 2 to 1, but all allowance made, daylight appeared to be about twice as effective as electric light. It was evident, however, that the electric light was not well placed for giving out its power advantageously. The nights being cold, and the plants under experiment for the most part of a character to require a hot moist atmosphere, the glass was covered very thickly with moisture, which greatly obstructed the action of the light, besides which, the electric light had to pass through the glass of its own lamp.* Notwithstanding these drawbacks, electric light was clearly sufficiently powerful to form chlorophyl and its derivatives in the plants. It was interesting to observe that the mustard-seed stem, when placed obliquely, turned completely towards the light in the course of two or three hours, and that cucumber and melon plants were affected in the same way, though at a slower rate. The cucumber and melon plants which have been

* Professor Stokes has shown, in 1853, that the electric arc is particularly rich in highly refrangible invisible rays, but that on passing the rays through glass, all those of high refrangibility are found to have been absorbed.

exposed to both day and electric light have made great progress, and my gardener, Mr. D. Buchanan, says that he could not have brought on the latter, without the aid of electric light, during the early winter. Some of these commenced to blossom on the 14th of February.

These preliminary trials go to prove that electric light can be utilized in aid of solar light by placing it over greenhouses, but the loss of effect in such cases must be considerable. I, therefore, directed my observations, in the next place, to the effect of electric light upon plants, when both were placed in the same apartment. A section of the melon house, already referred to (7′ 3″ × 3′ 3″, 2·21 m. × 0·19 m.), was completely darkened by being covered in with thick matting, and was whitewashed inside. The electric light was placed over the entrance door, and shelves were put down, in a horse-shoe form, to receive the pots containing the plants to be exposed to the action of electric light, the plants being placed at distances from the lamp varying from 0·5 metre to 2 metres. Upon the first occasion of trying the naked electric light in this manner, some of the plants, and especially some melon and cucumber plants, from 20 centims. to 40 centims. in height, which were within a metre distance from the lamp, commenced to suffer; those leaves which were directly opposite the light turning up at the edges and presenting a scorched appearance. On subsequent nights, therefore, the stands were so arranged that the distance of the plants from the light varied from 1·5 metres to 2·3 metres. The plants under experiment were divided into three groups; one group was exposed to daylight alone, a second similar group was exposed to electric light during eleven hours of the night, and were kept in the dark chamber during the day time, and the third similar group was exposed to eleven hours' day and eleven hours' electric light. These experiments were continued during four days and nights consecutively, and the results observed are of a very striking and decisive character, as regards the behaviour of such quick-growing plants as mustard, carrots, &c. The experiment was unsatisfactory in this one respect, that during the third night the gas-engine working the dynamo-machine came to a standstill, owing to a stoppage in one of the gas channels, and thus more than half the electric-light influence that night was lost to the plants. But, notwithstanding this drawback, the two groups of plants showed unmistakably the beneficial influence of electric light. The plants that had been exposed to daylight alone (comprising a fair proportion of sunlight) presented their usually healthy green appearance; those exposed to electric light alone were, in most instances, of a somewhat lighter, but, in one instance, of a somewhat darker hue than those exposed to daylight; and all the plants that had the double benefit of day and electric light far surpassed the others in darkness of green and vigorous appearance generally. A fear had been expressed that the melon and

cucumber plants, which had been scorched by excess of electric light on the first evening, would droop or die if further exposed to that agency, but I insisted upon their being placed within the influence of the electric light, at a distance from it exceeding 2 metres, and all of them have shown signs of recovery, throwing out fresh leaves and pearls of moisture at their edges. A pot of tulip buds was placed in this electric stove, and the flowers were observed to open completely after two hours' exposure.

One object I had in view in this experiment, was to observe whether the carbonic acid and nitrogenous compounds produced within the electric arc exercised any deleterious action upon the plants. All continuous access of air into the stove was closed, and in order to prevent excessive accumulation of heat, the stove pipes were thickly covered with matting and wet leaves. But although the access of stove heat was thus virtually stopped, the temperature of the house was maintained throughout the night at 72° F., proving that the electric lamp furnished not only a supply of effective light, but of stove heat also. No hurtful effect was moreover observed on the plants from the want of ventilation, and it would appear probable that the supply of pure carbonic acid resulting from the complete combustion of the carbon electrodes at high temperature, and under the influence of an excess of oxygen, sufficed to sustain their vital functions. If the nitrogenous compounds which Professor Dewar has shown to be developed in the electric arc were produced in large quantities, injurious effects upon the plants must undoubtedly ensue, but it can be shown that in a well-conditioned electric lamp, with a free circulation of air round the carbon electrodes, the amount of these products is exceedingly small, and of a different nature than is produced in a confined space. They could not indeed be perceived by their smell in the stove, when all ventilators were closed, and no injurious effects from them have hitherto been observed in the plants.

These experiments are not only instructive in proving the sufficiency of electric light alone to promote vegetation, but they also go to prove the important fact that diurnal repose is not necessary for the life of plants, although the duration of the experiments is too limited perhaps to furnish that proof in an absolute manner. It may, however, be argued from analogy, that such repose is not necessary, seeing that crops grow and ripen in a wonderfully short space of time in the northern regions of Sweden and Norway, and Finland, where the summer does not exceed two months, during which period the sun scarcely sets.

The next step in the course of these experiments was to remove the electric lamp into a palm house, constructed of framed glass, which was 28 ft. 3 in. long, 14 ft. 6 in. wide, and averaging 14 ft. 6 in. (8·62 m. × 14·42 m. × 4·42) in height. In the centre of this house

a banana palm, and a few other small palm trees are planted, the sides of the house all round being occupied with a considerable variety of flowering plants. The electric light was fixed as high as practicable at the south corner of the house, in order that its rays might fall upon the plants from a direction and at an angle coincident with those of the sun during the middle of the day. A metal reflector was placed behind the lamp in order to utilize the electric rays as much as possible. Along the eastern side of the house are some young vines, having their roots in a bed outside. Three pots of nectarine plants, just beginning to bud, were placed on the floor at various distances from the electric light, and also some rose plants, geraniums, orchids, &c. The temperature of the house was maintained at 65 F., and the electric lamp was kept alight from 5 p.m. to 6 a.m., for one week, from February 18th to February 24th, excepting Sunday night. The time was hardly sufficient to produce very striking effects, but all the plants continued to present a healthy appearance. Of three Alicante vines, the one nearest the electric light made most progress, and the same could be said of the nectarines and roses. It was observed that other plants, such as geraniums, continued to exhibit a vigorous appearance, notwithstanding the heat of the place. The electric light appeared to impart the vitality necessary to prevent a collapse of the organism through excessive temperature. This experiment is of importance in showing that the electric light if put into conservatories or greenhouses does not injure the plants, but rather improves their appearance and growth. The leaves assume a darker and more vigorous appearance, and it seems that the colouring of the flowers becomes more vivid, but a further period of time is necessary to establish this observation absolutely. The effects producible by electric light in conservatories is very striking, owing to the clear definition of form and colour produced, far exceeding that of ordinary daylight.

No further results of any particular interest could be expected from a continuance of this experiment, and I decided to try the effect of electric light as a means of promoting growth in the open air and under glass at the same time. The regulator was put back into its first position, 2 metres above the ground, with a sunken melon house on one side, and a sunken house containing roses, lilies, strawberries, and a variety of other plants on the other. The space of ground between these, about 1 metre broad, and 7 metres long, was covered with boxes sown with early vegetables, including mustard, peas, beans, and potatoes, and in order to prevent cold winds from injuring the plants, low protecting walls were put up across the openings of the passage between the two houses. The effect of electric light could thus be observed at the same time, upon the melon and cucumber plants in the one house, upon the roses, strawberries, &c., at an

inferior temperature in the other, and upon the early vegetables unprovided with covering.

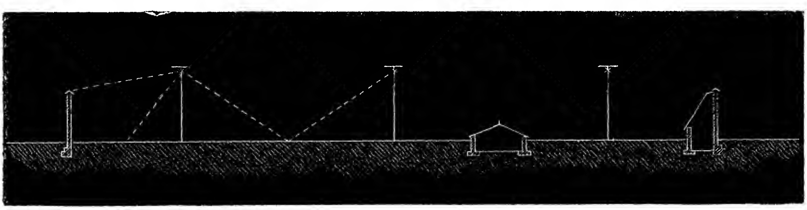
Some weeks must elapse before any absolute results can be given, but growth is evidently promoted under all these various circumstances. In order to test this clearly, a portion of the plants both under glass and in the open air are shaded from the electric light without removing them from their position of equal temperature, and exposed to solar light during daytime. The effect upon the flowering plants is very striking, electric light being apparently more efficacious to bring them on than daylight. Although the amount of heat given off from the electric arc is not great compared with a gas flame (giving off its products of combustion), yet the rays of intense heat of the arc counteract that loss of heat by radiation from the leaves into space, which during a clear night causes hoar frost. For this reason I expect that electric light may be usefully employed in front of fruit walls, in orchards and in kitchen gardens, to save the fruit-bud at the time of setting; and in this application electric light will probably be found a useful agent not only to promote rapid growth, but to insure a better yield of fruit. Experience alone can determine absolutely the effect of electric light upon the ripening of delicate fruit, but considering its evident power to form chlorophyl, there seems no reason to suppose that its action would not also in this case resemble that of the sun, and that saccharine matter, and more especially the aromatic constituents, would be produced. In this country solar light is too often found insufficient to ripen the fruit or even the wood of fruit trees during the short summer months; and I believe that electric light will be found a most useful auxiliary to solar light to effect the production of ripe and aromatic fruit both under glass and in the open air.

Estimated Cost of Electro-Horticulture.

A very important question is that of the cost of electro-horticulture. This will depend in a great measure upon the cost of the fuel or other source of energy, and upon the scale of application. To work only one electric lamp by means of a small steam or gas engine is expensive both in fuel and in cost of attendance. If steam-power has to be resorted to, an engine of sufficient size should be employed to give economical results per horse-power of energy produced, and the electric arc should be of sufficient brilliancy to give a good effect for the power expended. Experience in electric illumination has established a form and size of machine, both convenient and suitable for the attainment of economical results, viz., the medium dynamo-electric machine, which, if applied to a suitable regulator, produces fully 6,000 candle-power of diffused light with an expenditure of 4 horse-power.

The experiments before given show that the most effective height

at which to place the naked electric light of 1,400 candle-power is about 2 metres. By providing a metallic reflector, and thus throwing the major portion of the upward rays down upon the surface to be illuminated that height may be taken at 3 metres. If the electric arc employed was equal to 6,000 candles, the height would be $\frac{\sqrt{6,000}}{\sqrt{1,400}} \times 3 = 6{\cdot}2$ metres, at which such an electric light should be fixed under the protection of a tin plate or other reflector. In operating upon an extended surface several lamps should be placed at such distances apart, as to make the effect over it tolerably uniform. The effect of radiation would be equally distributed over the ground if the radiating centres were placed at distances apart equal to double their height above the ground; for under these circumstances a square foot of surface midway between them would receive from each centre one-half the number of rays falling upon such a surface immediately below a centre. A plant at the intermediate point would, however, have the advantage of presenting a larger leaf surface to the two sources of light; and in order to compensate for this advantage, the light centres may be placed considerably further apart, say at distances equal to three times their elevation, or 18 metres. Nine lights so placed would cover an area 54 metres square, or just about $\frac{3}{4}$ acre. If this space was enclosed with a high fruit wall (as shown with the lamp centres marked in the accompanying sketch), this will also get the full benefit of electric



radiation, and would serve at the same time to protect the plants from winds. Protection against injury from this latter cause might be further carried out with advantage by following plan adopted (with excellent results I believe) by Sir William Armstrong, that of subdividing the area under forced cultivation by vertical partitions of glass.

The engine-power necessary to maintain this radiant action would be $9 \times 4 = 36$ horse-power, involving the consumption of $36 \times 2\frac{1}{2} = 90$ lbs. of fuel per hour, or say, for a night of 12 hours (with an allowance of 40 lbs. for getting up steam) 10 cwt., which, at sixteen shillings per ton, would cost eight shillings. This expenditure would not include, however, the cost of carbons and of an attendant, which would probably amount to another eight shillings, making a total of

sixteen shillings. If, however, an engine can be found doing other descriptions of work during the day time, the cost of steam power and attendance for the night-work only would be considerably reduced. In the calculation just given, I have assumed the employment of fuel for the production of mechanical energy, whereas the question will assume a totally different aspect if natural sources of power, such as waterfalls, can be made available within the reasonable distance of half-a-mile. The expenditure for energy will, in that case, be almost entirely saved, and that of attendance be greatly diminished, and under such circumstances it seems probable that electro-horticulture may be carried out with considerable advantage.

The experiments furnish proof that the management of the electrical apparatus presents no particular difficulty, as the gas-engine, dynamo-machine, and regulator have been under the sole management of my head gardener, Mr. D. Buchanan, and his son an assistant gardener. The regulator requires no attention beyond the replacement of carbons every four or five hours, which period may easily be increased to twelve hours, by a slight modification of the lamp.

Conclusions.

The experiments seem to lead to the following conclusions:—

1. That electric light is efficacious in producing chlorophyl, in the leaves of plants, and in promoting growth.

2. That an electric centre of light, equal to 1,400 candles, placed at a distance of 2 metres from growing plants, appeared to be equal in effect to average daylight at this season of the year, but that more economical effects can be attained by more powerful light centres.

3. That the carbonic acid and nitrogenous compounds generated in diminutive quantities in the electric arc, produce no sensible deleterious effects upon plants enclosed in the same space.

4. That plants do not appear to require a period of rest during the twenty-four hours of the day, but make increased and vigorous progress if subjected during daytime to sunlight and during the night to electric light.

5. That the radiation of heat from powerful electric arcs can be made available to counteract the effect of night frost, and is likely to promote the setting and ripening of fruit in the open air.

6. That while under the influence of electric light, plants can sustain increased stove heat without collapsing, a circumstance favourable to forcing by electric light.

7. That the expense of electro-horticulture depends mainly upon the cost of mechanical energy, and is very moderate where natural sources of such energy, such as waterfalls, can be made available.

Since writing the above my attention has been drawn to an article in "Nature," 29th January, 1880, giving interesting observations by

Dr. Schübeler, of Christiania, on "The Effect of Uninterrupted Sunlight on Plants in the Arctic Regions." These observations fully confirm the conclusion indicated by my experiments with electric light. Not only are plants able to grow continuously, according to Dr. Schübeler, but when under the influence of continuous light they develop more brilliant flowers and larger and more aromatic fruit than under the alternating influence of light and darkness, whereas the formation of sugar appears to be dependent chiefly upon temperature.

It would follow from these observations, that with the aid of stoves and electric light, fruit, excelling both in sweetness and aroma, and flowers of great brightness, may be grown without solar aid. Dr. Schübeler mentions that in removing an Acacia plant from the dark, and placing it under the influence of the arctic midnight sun, the leaves opened slowly, and it is interesting to observe that the same effect took place when an *Acacia lophantha* was placed (in the open air) under the influence of my midnight lamp.

March 11, 1880.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. The Croonian Lecture.—"On some Elementary Principles in Animal Mechanics. No. IX. The Relation between the Maximum Work done, the Time of Lifting, and the Weights Lifted by the Arms." By the Rev. Samuel Haughton, M.D. (Dubl.), D.C.L. (Oxon.), F.R.S., Fellow of Trinity College, Dublin. Received February 28, 1880.

In the preceding note (No. VIII) I have shown that, in lifting weights at a fixed rate with the arms, until fatigue sets in, the following equation, deduced from the law of fatigue, is complied with, very closely:—

$$\frac{n(1+\beta^2 t^2)}{t}=A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$